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XR4151

Voltage-to-Frequency Converter

March 1991-1

FEATURES

- Single Supply Operation (+8V to +22V)
- Pulse Output Compatible with All Logic Forms
- Programmable Scale Factor (K)
- Linearity ±0.05% Typical-precision Mode
- Temperature Stability ±100% ppm/°C Typical
- High Noise Rejection
- Inherent Monotonicity
- Easily Transmittable Output
- Simple Full Scale Trim
- Single-Ended Input, Referenced to Ground
- Also Provides Frequency-to-Voltage Conversion
- Direct Replacement for RC/RV/RM-4151

APPLICATIONS

- Voltage-to-Frequency Conversion
- A/D and D/A Conversion
- Data Transmission
- Frequency-to-Voltage Conversion
- Transducer Interface
- System Isolation

GENERAL DESCRIPTION

The XR4151 is a device designed to provide a simple, low-cost method for converting a DC voltage into a proportional pulse repetition frequency. It is also capable of converting an input frequency into a proportional output voltage. The XR4151 is useful in a wide range of applications including A/D and D/A conversion and data transmission.

ORDERING INFORMATION

Part No.	Package	Operating Temperature Range
XR4151P	8 Lead 300 Mil PDIP	-40°C to +85°C
XR4151CP	8 Lead 300 Mil PDIP	0°C to +70°C
XR4151MD	8 Lead 4.4mm EIAJ SOP	0°C to +70°C

BLOCK DIAGRAM

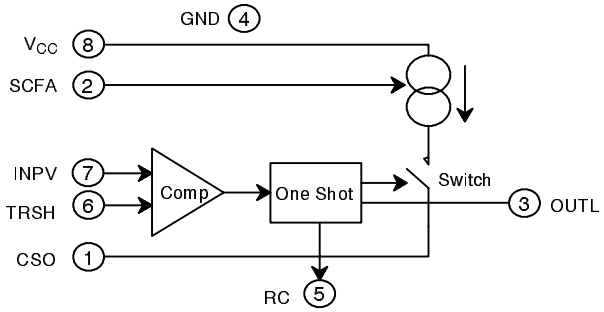
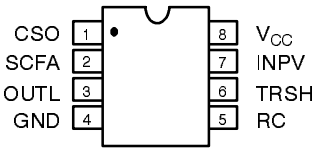
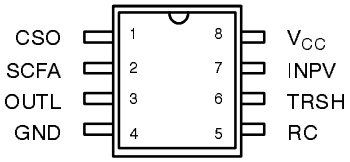


Figure 1. Block Diagram

PIN CONFIGURATION



8 Lead PDIP (0.300")



8 Lead SOP (EIAJ, 4.4mm)

PIN DESCRIPTION

Pin #	Symbol	Type	Description
1	CSO	O	Current Source Output.
2	SCFA	I	Scale Factor Input.
3	OUTL	O	Logic Output.
4	GND		Supply Ground.
5	RC	I	One Shot Timing Input.
6	TRSH	I	Comparator Input.
7	INPV	I	Input Voltage.
8	V_{CC}	O	Positive Supply.

ELECTRICAL CHARACTERISTICS

Test Conditions: V_{CC} = 15V, T_A = +25°C, Unless Otherwise Specified

Parameter	Min.	Max.	Typ.	Unit	Conditions
Supply Current					
XR4151MD, CP	**2.0**	**6.0**	3.5	mA	8V < V_{CC} < 15V
	2.0	**7.5**	4.5	mA	15V < V_{CC} < 22V
XR4151P	**2.0**	**7.4**	4.5	mA	15V < V_{CC} < 22V
Conversion Accuracy Scale Factor					
XR-4151MD, CP	**0.90**	**1.10**	1.00	kHz/V	Circuit of *Figure 2*, V_I=10V
XR-4151P	**0.92**	**1.08**	1.00	kHz/V	RS=14.0K
Drift With Temperature			± 100	ppm/°C	Circuit of *Figure 2*, V_I=10V
Drift With V_{CC}					
XR4151MD, CP			0.2	%/V	Circuit of *Figure 2*, V_I=1.0V
XR4151P	**-0.9**	**0.9**	0.2	%/V	8V < V_{CC} < 18V
Input Comparator					
Offset Voltage		**10**	5	mV	
Offset Current		**± 100**	± 50	nA	
Input Bias Current		**-300**	-100	nA	
Common Mode Range[1]	0	**V_{CC} -3**	0 to V_{CC} -2	V	
One-Shot					
Threshold Voltage, Pin 5	**0.63**	0.70	**0.667**	xV_{CC}	
Input Bias Current, Pin 5		**-500**	-100	nA	
Reset V_{SAT}		**0.5**	0.15	V	Pin 5= 2.2mA
Current Source					
Output Current			**138.7**	µA	Pin 1, V=0, RS=14.0kΩ
Change With Voltage		**2.5**	1.0	µA	Pin 1, V=0V to V=10V
Off Leakage		**50**	0.15	nA	Pin 1, V=0V
Reference Voltage	**1.80**	**2.28**	2.05	V	Pin 2
Logic Output					
V_{SAT}		**0.50**	0.15	V	Pin 3, 1=3.0mA
V_{SAT}		**0.30**	0.10	V	Pin 3, 1=2.0mA
Off Leakage		**1.0**	0.1	µA	

Notes

[1] *Input Common Mode Range includes ground.*

***Bold face parameters** are covered by production test and guaranteed over operating temperature range.*

Specifications are subject to change without notice

ABSOLUTE MAXIMUM RATINGS

Power Supply 22V
Output Sink Current 20mA
Internal Power Dissipation 500mW
Input Voltage . . . . . -0.2V to $+V_{CC}$
Output Short Circuit to Ground . . . . . Continuous

SYSTEM DESCRIPTION

The XR4151 is a precision voltage-to-frequency converter featuring 0.05% conversion linearity (precision mode), high noise rejection, monotonicity, and single supply operation from 8V to 22V. An RC network on Pin 5 gets the maximum full wave frequency. Input voltage on Pin 7 is compared with the voltage on Pin 6 (which is generally controlled by the current source output, Pin 1). Frequency output is proportioned to the voltage on Pin 7. The current source is controlled by the resistance on Pin 2 (nominally 14kΩ with I = 2.05 V/R. The output is an open collector at Pin 3.

PRINCIPLES OF OPERATION

Single Supply Mode Voltage-to-Frequency Converter

In this application, the XR4151 functions as a stand alone voltage-to-frequency converter operating on a single positive power supply. Refer to the functional block diagram and *Figure 2*, the circuit connection for single supply voltage-to-frequency conversion. The XR-4151contains a voltage comparator, a one-shot, and a precision switched current source. The voltage comparator compares a positive input voltage applied at pin 7 to the voltage at pin 6. If the input voltage is higher, the comparator will fire the one-shot. The output of the one-shot is connected to both the logic output and the precision switched current source. During the one-shot period, T, the logic output will go low and the current source will turn on with current 1. At the end of the one shot period the logic output will go high and the current source will shut off. At this time the current source has injected an amount of charge $Q = I_O T$ into the network R_B-C_B. If this charge has not increased the voltage V_B such that $V_B > V_I$, the comparator again fires the one-shot and the current source injects another, Q, into the R_B-C_B network. This process continues until $V_B > V_I$. When this condition is achieved, the current source remains off and the voltage V_B decays until V_B is again equal to V_I. This completes one cycle. The VFC will now run in a steady state mode. The current source charges the capacitor C_B at a rate such that $V_B \geq V_I$. Since the discharge rate of capacitor C_B is proportional to V_B / R_B, the frequency at which the system runs will be proportional to the input voltage.

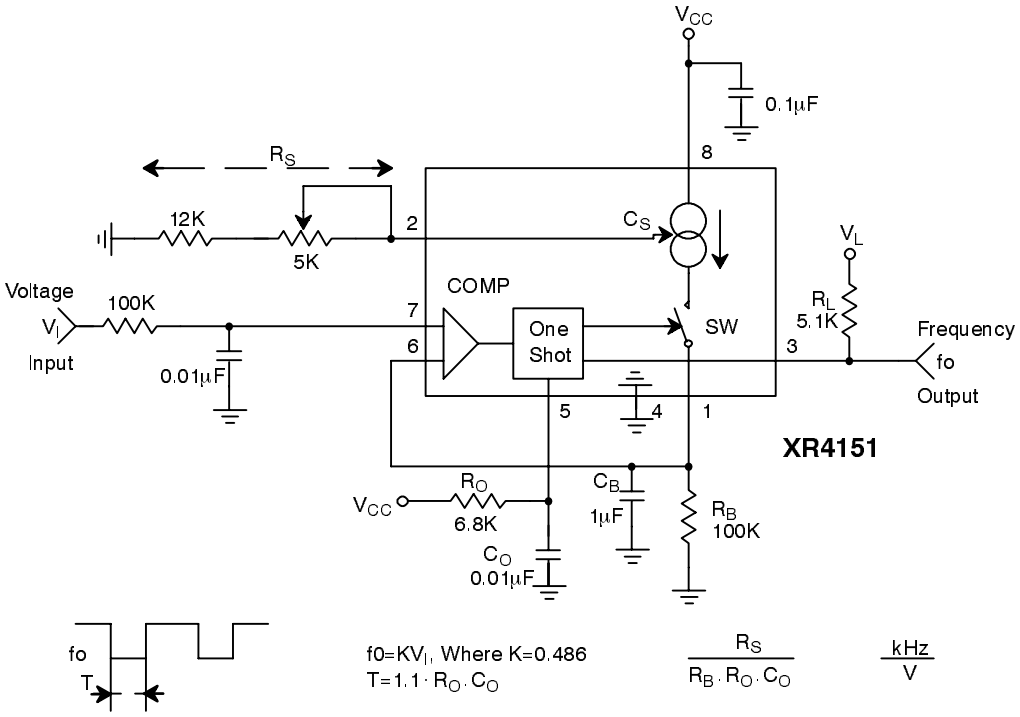


Figure 2. Voltage-to-Frequency Converter

TYPICAL APPLICATIONS

Single Supply Voltage-to-Frequency Converter

Figure 2 shows the simplest type of VFC that can be made with the XR4151. The input voltage range is from 0 to +10V, and the output frequency is from 0 to 10kHz. The full scale frequency can be tuned by adjusting R_S, the output current set resistor. This circuit has the advantage of being simple and low in cost, but it suffers from inaccuracy due to a number of error sources. Linearity error is typically 1%. A frequency offset will also be introduced by the input comparator offset voltage. Also, response time for this circuit is limited by the passive integration network R_BC_B. For the component values shown in *Figure 2,* response time for a step change input from 0 to +10V will be 135msec. For applications which require fast response time and high accuracy, use the circuit of *Figure 3*.

Precision Voltage-to-Frequency Converter

In this application (*Figure 3*) the XR4151 is used with an operational amplifier integrator to provide typical linearity of 0.05% over the range of 0 to -10V. Offset is adjustable to zero. Unlike many VFC designs which lose linearity below 10mV, this circuit retains linearity over the full range of input voltage, all the way to 0V.

Trim the full scale adjust pot at V_I = -10V for an output frequency of 10kHz. The offset adjust pot should be set for 10Hz with an input voltage of -10mV.

The operational amplifier integrator improves linearity of this circuit over that of *Figure 2* by holding the output of the source, Pin 1, at a constant 0V. Therefore, the linearity error due to the current source output conductance is eliminated. The diode connected around the operational amplifier prevents the voltage at pin 7 of the XR4151 from going below 0. Use a low-leakage diode here, since any leakage will degrade the accuracy. This circuit can be operated from a single positive supply if an XR3403 ground-sensing operational amplifier is used for the integrator. In this case, the diode can be left out. Note that even though the circuit itself will operate from a single supply, the input voltage is necessarily negative. For operations above 10kHz, bypass pin 6 of the XR4151 with .01μF.

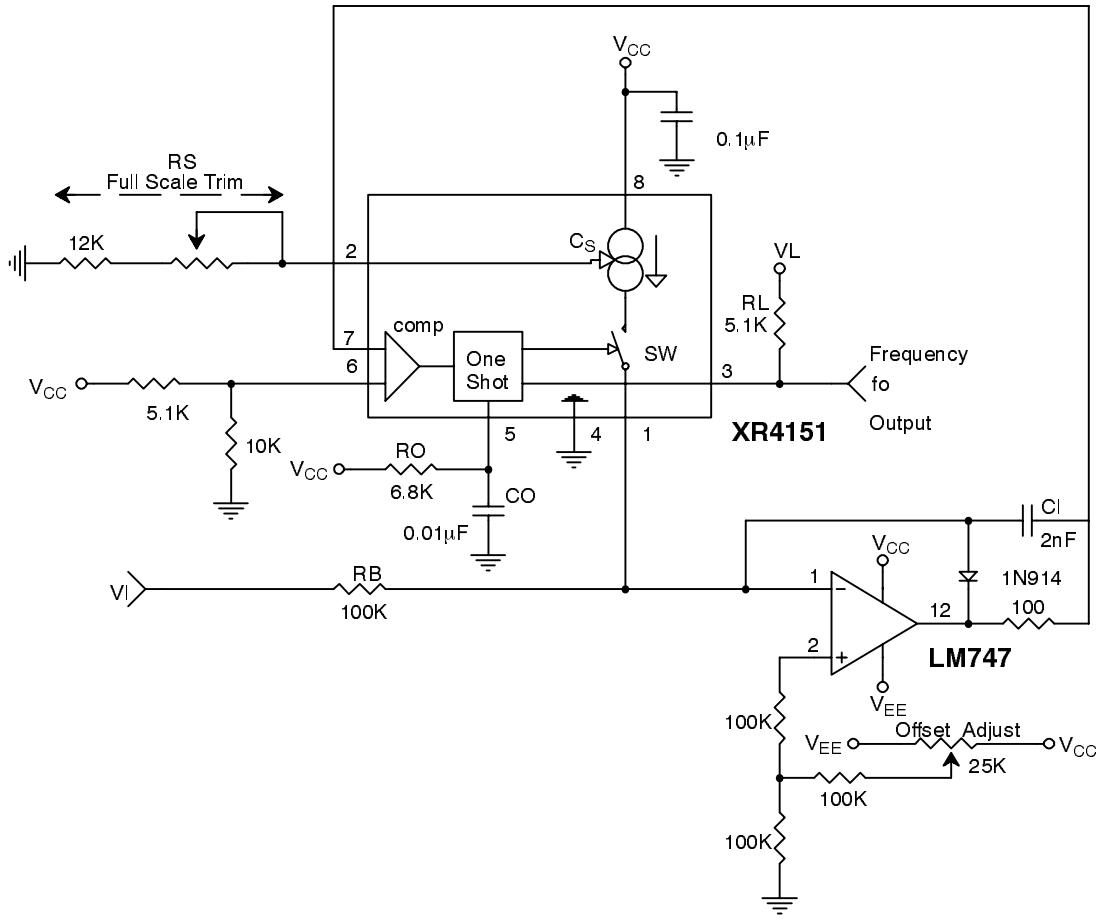


Figure 3. Precision Voltage to Frequency Converter

Frequency-to-Voltage Conversion

The XR4151 can be used as a frequency-to-voltage converter. *Figure 4* shows the single-supply FVC configuration. With no signal applied, the resistor bias networks tied to pins 6 and 7 hold the input comparator in the off state. A negative going pulse applied to pin 6 (or positive pulse to pin 7) will cause the comparator to fire the one-shot. For proper operation, the pulse width must be less than the period of the one-shot, $T = 1.1\ R_0C_0$. For a 5Vpp square-wave input the differentiator network formed by the input coupling capacitor and the resistor bias network will provide pulses which correctly trigger the one-shot. An external voltage comparator can be used to "square-up" sinusoidal input signals before they are applied to the XR4151. Also, the component values for the input signal differentiator and bias network can be altered to accommodate square waves with different amplitudes and frequencies. The passive integrator network R_BC_B filters the current pulses from the pin 1 output. For less output ripple, increase the value of C_B.

For increased accuracy and linearity, use an operational amplifier integrator as shown in *Figure 5*, the precision FVC configuration. Trim the offset to give -10mV out with 10Hz in and trim the full scale adjust for -10V out with 10kHz in. Input signal conditioning for this circuit is necessary just as for the single supply mode and the scale factor can be programmed by the choice of component values. A tradeoff exists between the amount of output ripple and the response time, through the choice or integration capacitor C_1. If $C_1 = 0.1\mu F$ the ripple will be about 100mV. Response time constant $\tau_R = R_BC_I$. For $R_B = 100k\Omega$ and $C_I = 0.1\mu F$, $\tau_R = 10msec$.

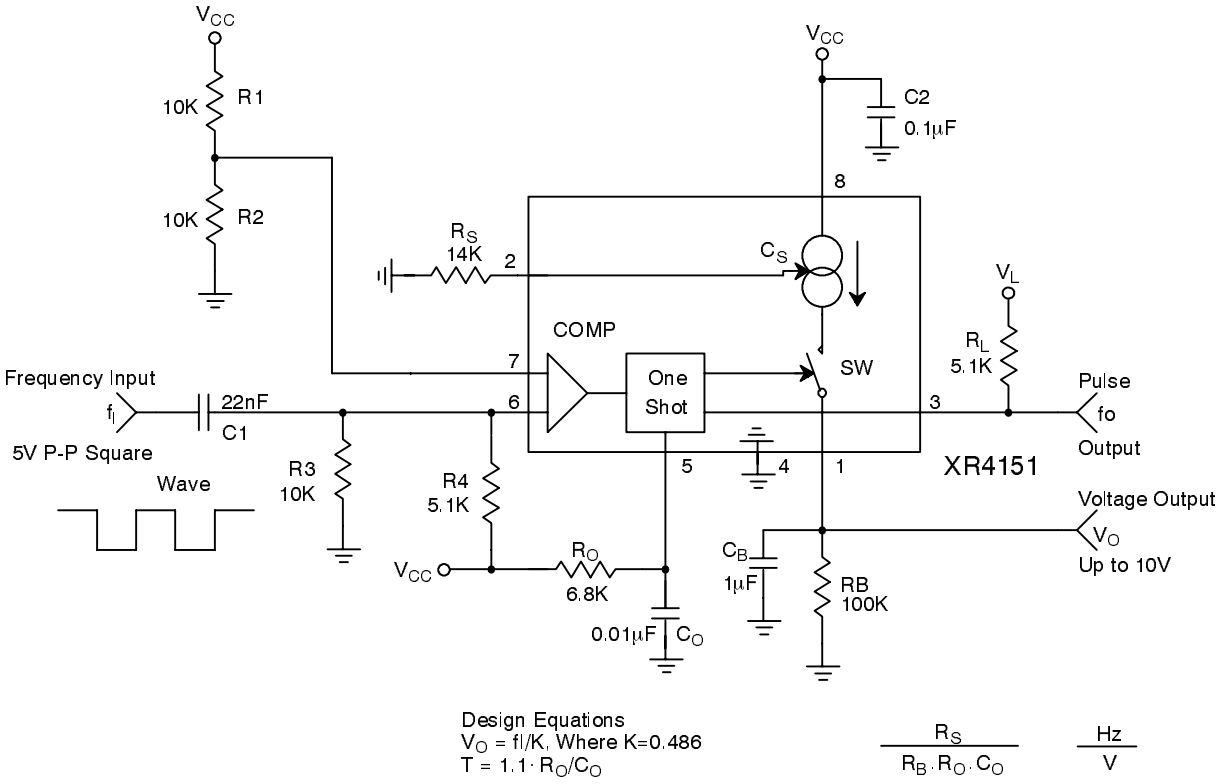


Figure 4. Frequency to Voltage Converter

Precautions

1. The voltage applied to comparator input pins 6 and 7 should not be allowed to go below ground by more than 0.3V.
2. Pins 3 and 5 are open-collector outputs. Shorts between these pins and V_{CC} can cause overheating and eventual destruction.
3. Reference voltage terminal pin 2 is connected to the emitter of an NPN transistor and is held at approximately 2.05V. This terminal should be protected from accidental shorts to ground or supply voltages. Permanent damage may occur if the current in pin 2 exceeds 5mA.
4. Avoid stray coupling between pins 5 and 7; it could cause false triggering. For the circuit of *Figure 2*, bypass pin 7 to ground with at least 0.01μF. This is necessary for operation above 10kHz.

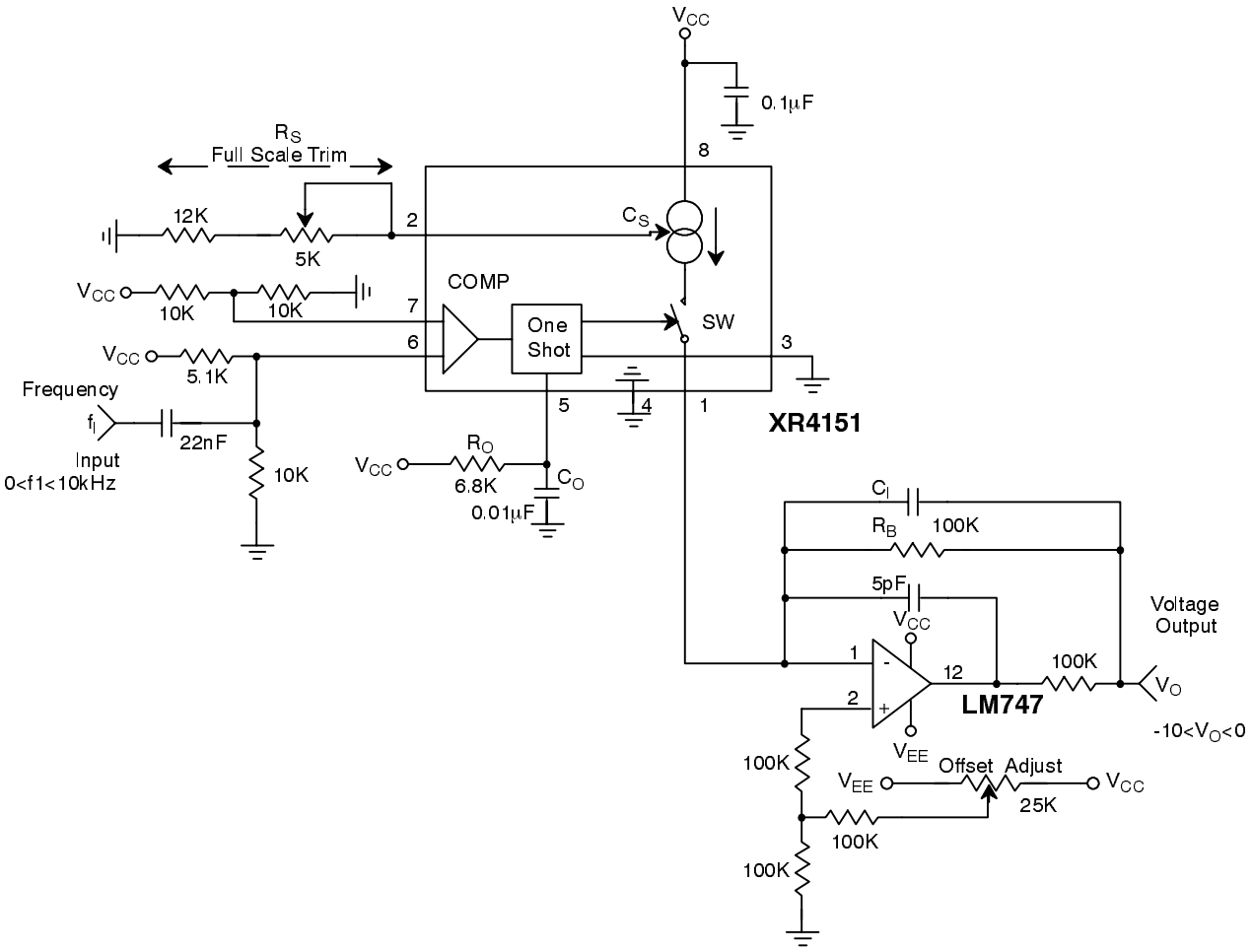


Figure 5. Precision Frequency-to-Voltage Converter

Programming the XR4151

The XR4151 can be programmed to operate with a full scale frequency anywhere from 1.0Hz to 100kHz. In the case of the VFC configuration, nearly any full scale input voltage from 1.0V and up can be tolerated if proper scaling is employed. Here is how to determine component values for any desired full scale frequency.

1. Set R_S = 14kΩ or use a 12K resistor and 5K pot as shown in the figures. (The only exception to this is *Figure 3*).
2. Set $T = 1.1 \cdot R_0 \cdot C_0 = 0.75[1/fo]$ where fo is the desired full scale frequency. For optimum performance make $6.8k\Omega > R_0 > 680k\Omega$ and $0.001\mu F < C_0 < 1.0\mu F$.
3. a) For the circuit of *Figure 2* make $C_B = 10^{-2}$ [1/fo] Farads.

   Smaller values of C_B will give a faster response time, but will also increase the frequency offset and nonlinearity.

   b) For the active integrator circuit make

   $C_I = 5 \times 10^{-5}$ [1/fo] Farads.

   The operational amplifier integrator must have a slew rate of at least 135×10^{-6} [$1/C_1$] volts per second where the value of C_1 is in Farads.
4. a) For the circuit of *Figure 3* keep the values of R_B as shown and use an input attenuator to give the desired full scale input voltage.

   b) For the precision mode circuit of *Figure 3*, set $R_B = V_{IO}/100\mu A$ where V_{IO} is the full scale input voltage.

   Alternately, the operational amplifier inverting input (summing node) can be used as a current input with the full scale input current I_{IO} = -100μA.
5. For the FVC's, pick the value of C_B or C_I to give the optimum tradeoff between the response time and output ripple for the particular application.

Design Example

I. Design a precision VFC (from *Figure 4*) with fo = 100kHz and V_{IO} = -10V.

1. Set R_S = 14.0kΩ.
2. $T = 0.75\ [1/10^5] = 7.5\mu sec.$

   Let R_0 = 6.8kΩ and C_0 = 0.001μF.
3. $C_I = 5 \times 10^{-5}\ [1/10^5] = 500pF.$

   Op amp slew rate must be at least

   $SR = 135 \times 10^{-6}\ [1/500pF] = 0.27V/\mu sec.$
4. $R_B = 10V/100\mu A = 100k\Omega.$

II. Design a precision VFC with fo = 1Hz and V_{IO} = 10V.

1. Let R_S = 14.0kΩ.
2. T = 0.75 [1/1] = 0.75 sec.

   Let R_0 = 680kΩ and C_0 = 1.0μF.
3. $C_I = 5 \times 10^{-5}$ [1/1]F = 50μF.
4. R_B = 100kΩ.

III. Design a single supply FVC to operate with a supply voltage of 9V and full scale input frequency fo = 83.3Hz. The output voltage must reach at least 0.63 of its final value in 200msec. Determine the output ripple.

1. Set R_S = 14.0kΩ.
2. T = 0.75 [1183.3] = 9msec.

   Let R_0 = 82kΩ and C_O = 0.1μF.
3. Since this FVC must operate from 8.0V, we shall make the full scale output voltage at pin 6 equal to 5.0V.
4. $R_B = 5V/100\mu A = 50k\Omega.$
5. Output response time constant is $\tau_R \leq$ 200msec.

   Therefore,

   $C_B \leq \tau_R/R_B = (200 \times 10^{-3})/(50 \times 10^3) = 4\mu F.$

   Worst case ripple voltage is

   $V_R = (9ms \times 135\mu A)/4\mu F = 304mV.$

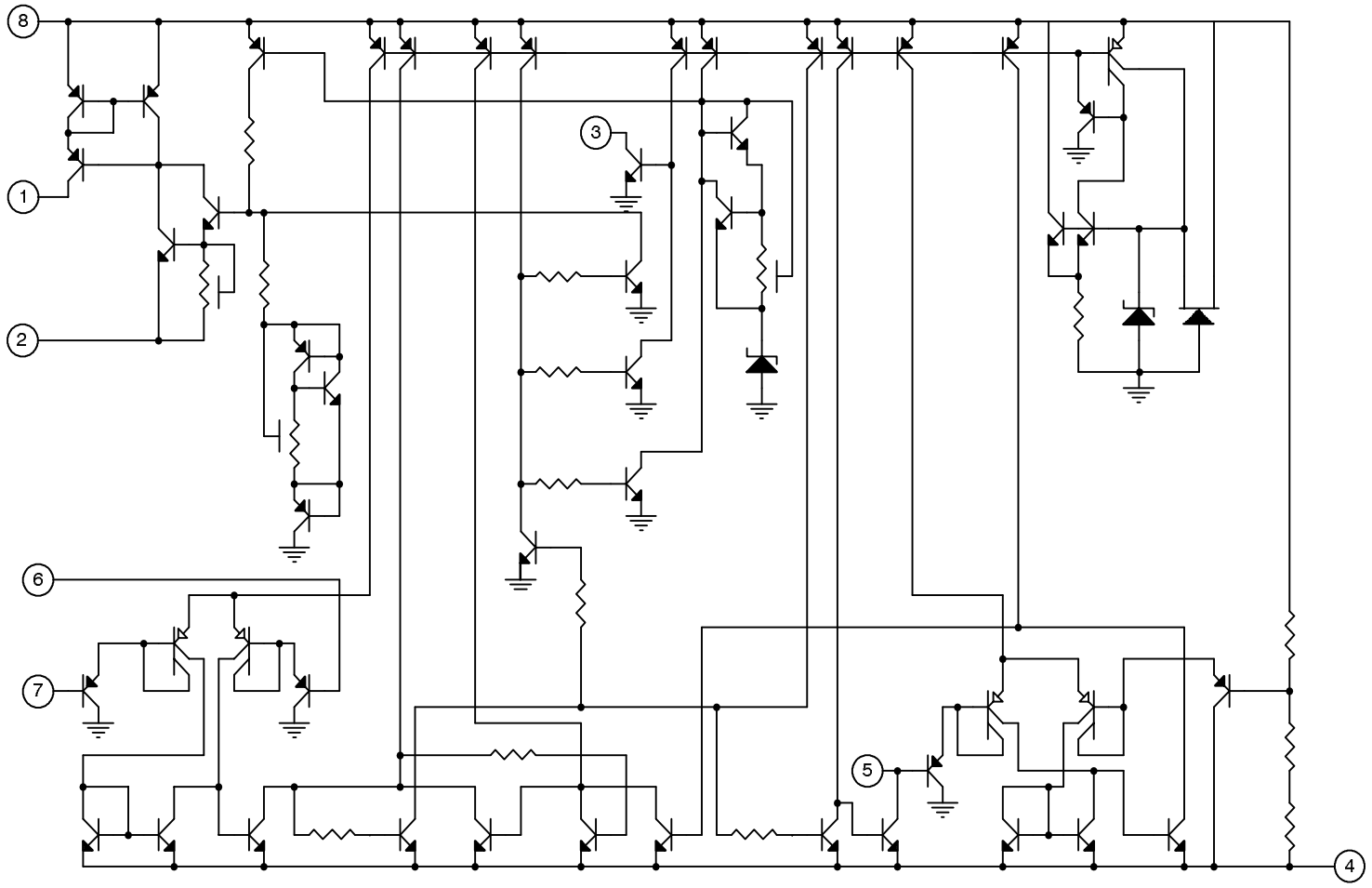
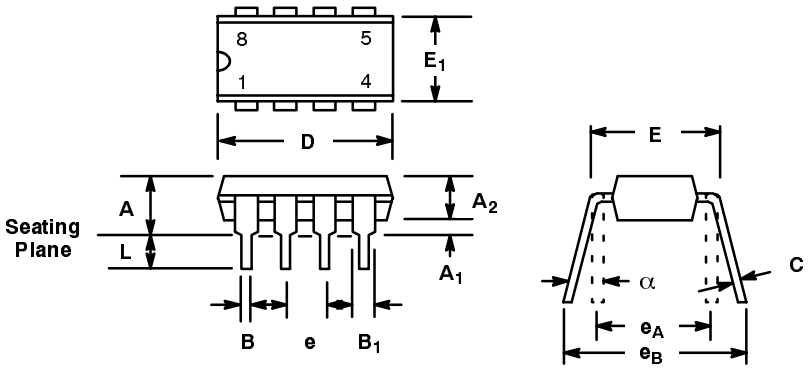


Figure 6. Equivalent Schematic Diagram

8 LEAD PLASTIC DUAL-IN-LINE (300 MIL PDIP)

Rev. 1.00

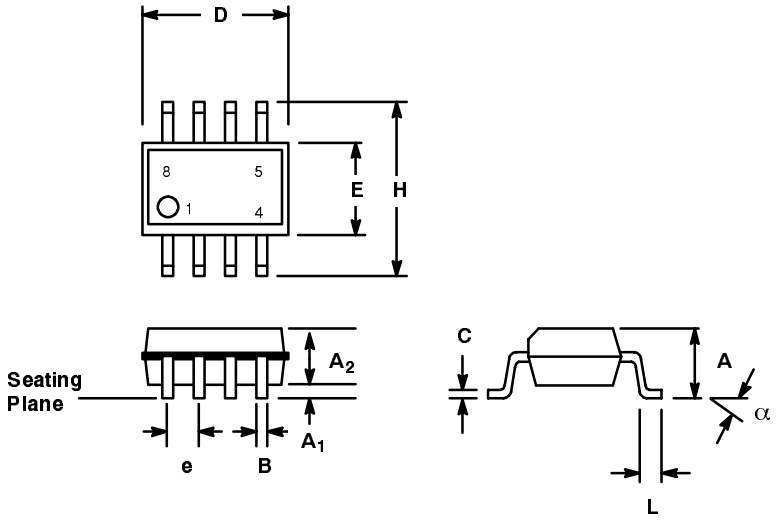


SYMBOL	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.145	0.210	3.68	5.33
A_1	0.015	0.070	0.38	1.78
A_2	0.015	0.195	2.92	4.95
B	0.014	0.024	0.36	0.56
B_1	0.030	0.070	0.76	1.78
C	0.008	0.014	0.20	0.38
D	0.348	0.430	8.84	10.92
E	0.300	0.325	7.62	8.26
E_1	0.240	0.280	6.10	7.11
e	0.100 BSC		2.54 BSC	
e_A	0.300 BSC		7.62 BSC	
e_B	0.310	0.430	7.87	10.92
L	0.115	0.160	2.92	4.06
α	0°	15°	0°	15°

Note: The control dimension is the inch column

8 LEAD EIAJ SMALL OUTLINE
(4.4 mm EIAJ SOP)

Rev. 1.00



SYMBOL	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.057	0.071	1.45	1.80
A_1	0.002	0.008	0.05	0.20
A_2	0.055	0.063	1.40	1.60
B	0.012	0.020	0.30	0.50
C	0.004	0.008	0.10	0.20
D	0.193	0.201	4.90	5.10
E	0.169	0.177	4.30	4.50
e	0.050 BSC		1.27 BSC	
H	0.236	0.252	6.00	6.40
L	0.012	0.030	0.30	0.76
α	0°	10°	0°	10°

Note: The control dimension is the millimeter column

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